Drainage Management Status

3

Overview

Since publication of the 1990 *Plan*, government agencies, irrigation and drainage districts, wetland managers, and individual growers have made progress in implementing SJVDP recommendations. Environmental interest groups have also been working closely with the above groups to further the implementation of *Plan* recommendations. Because the drainage-impacted area of the Valley is so large and involves numerous entities and individual irrigators, this Status Report highlights only major implementation efforts.

SJVDP estimated deep percolation on the west side of the Valley to vary from 0.90 to 1.05 acre-feet per acre per year. The assumption was made that 0.30 af/a/y is the average drainage water needed for salt leaching; this is also the estimated amount that percolates through the Corcoran Clay (a thick clay layer underlying most of the lands on the west side of the San Joaquin Valley). Combinations of options specific to the subarea including source control, discharge to the San Joaquin River, groundwater management, reuse, and evaporation systems could manage 0.6 to 0.75 af/a/y (0.90-0.30 or 1.05-0.30). Source control could be universally applied to reduce deep percolation by 0.20 to 0.35 af/a/y. The balance of 0.40 af/a/y could be collected and reduced by other management measures mentioned above. Land retirement was an option to isolate selenium-contaminated areas and to achieve deep-percolation reductions for a given subarea. The 133,000 acres of tile-drained land existing in 1990 was projected to increase to about 760,000 acres by 2040. SJVDP recommendations for 2000 are compared to accomplishments by 1996 in Table 1.

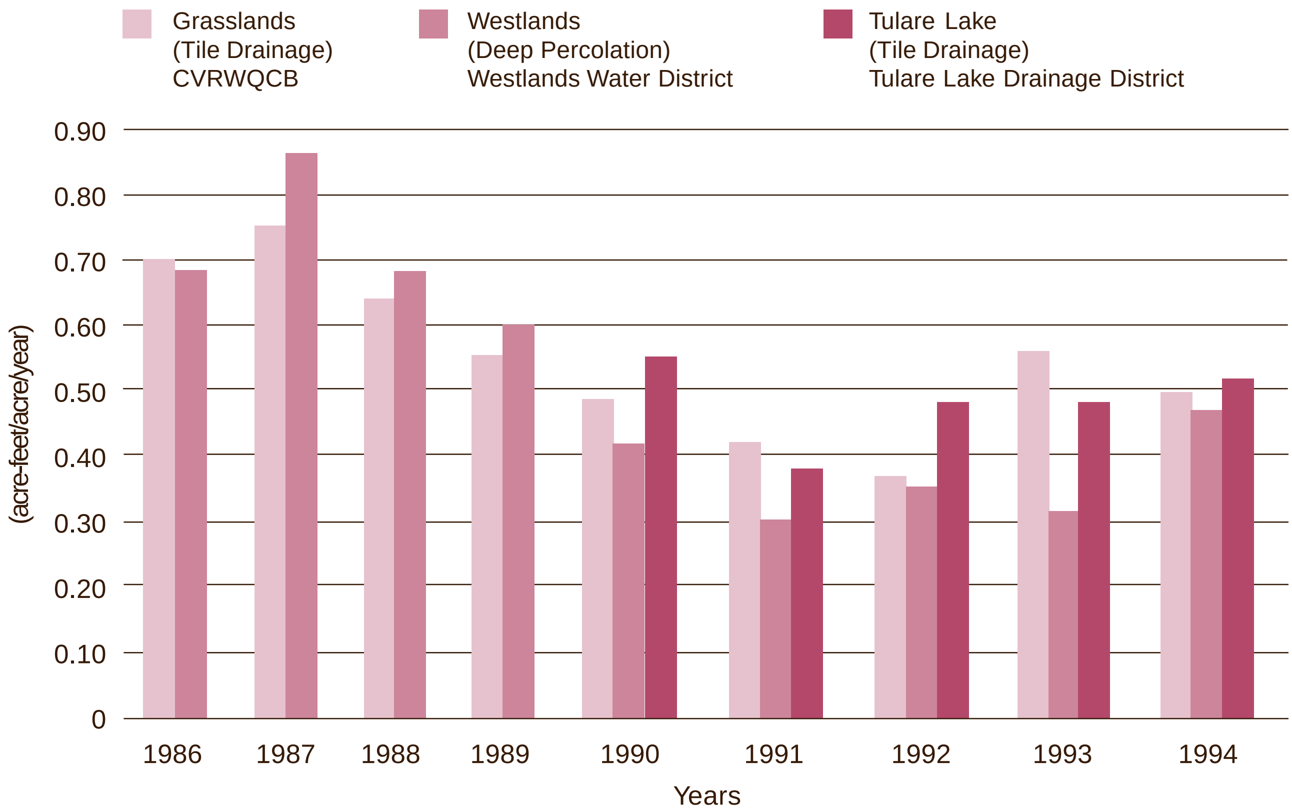
Source Control

Source control, an integral part of efficient water management/conservation, is a key component of in-valley drainage management that can significantly reduce drainage water volume. The Central Valley Project Improvement Act of 1992 requires water districts in federal water service areas to prepare water conservation plans.

The Central Valley Regional Water Quality Control Board compiled drainage-related data from 1986 through 1994 for the San Joaquin River basin (CVRWQCB, August 1995), essentially the same as the Grasslands subarea identified by SJVDP. The report indicates that total drainage volume, tile drainage volume, and selenium loads generally decreased from 1986 to 1992 but increased in 1993, a wet year.

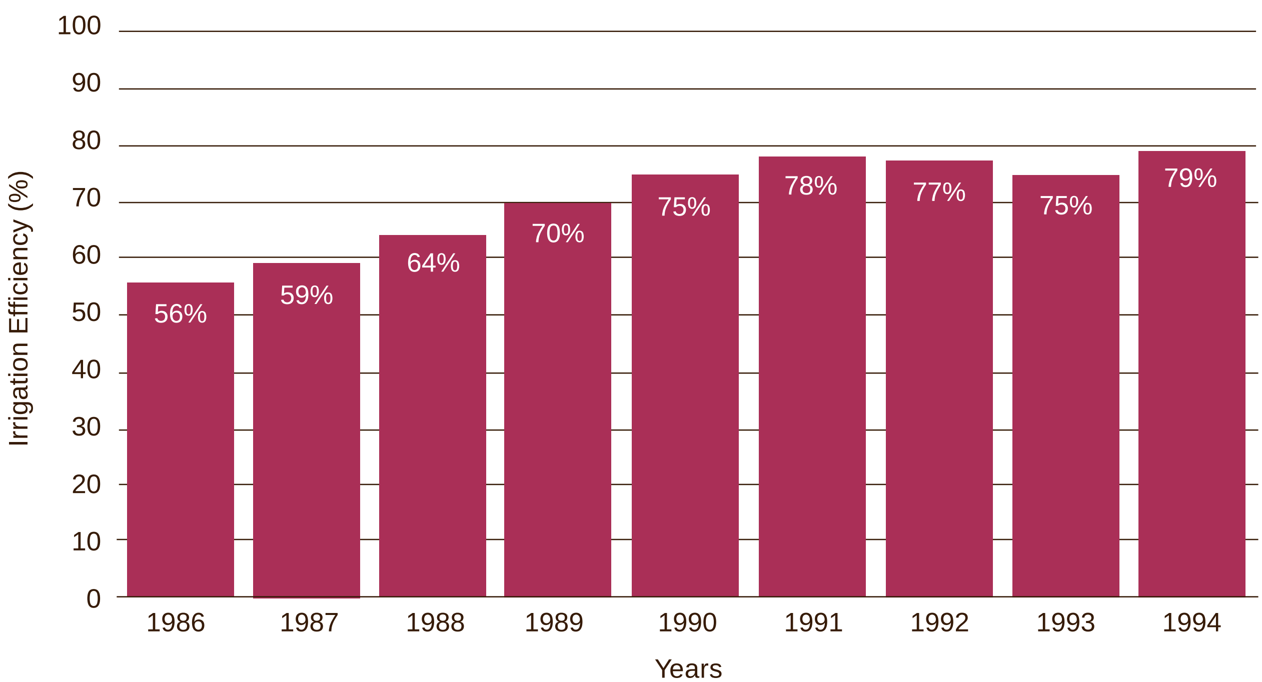
Figure 3 shows CVRWQCB estimates of tile drainage yield for the Grasslands subarea,

Figure 3—Estimate of Subsurface (af/a/y) Drainage Yield for Three Areas in the San Joaquin Valley



(SJVDP Drainage Yield Target is 0.4 af/a/y)

Figure 4—Regional Irrigation Efficiency in Grasslands



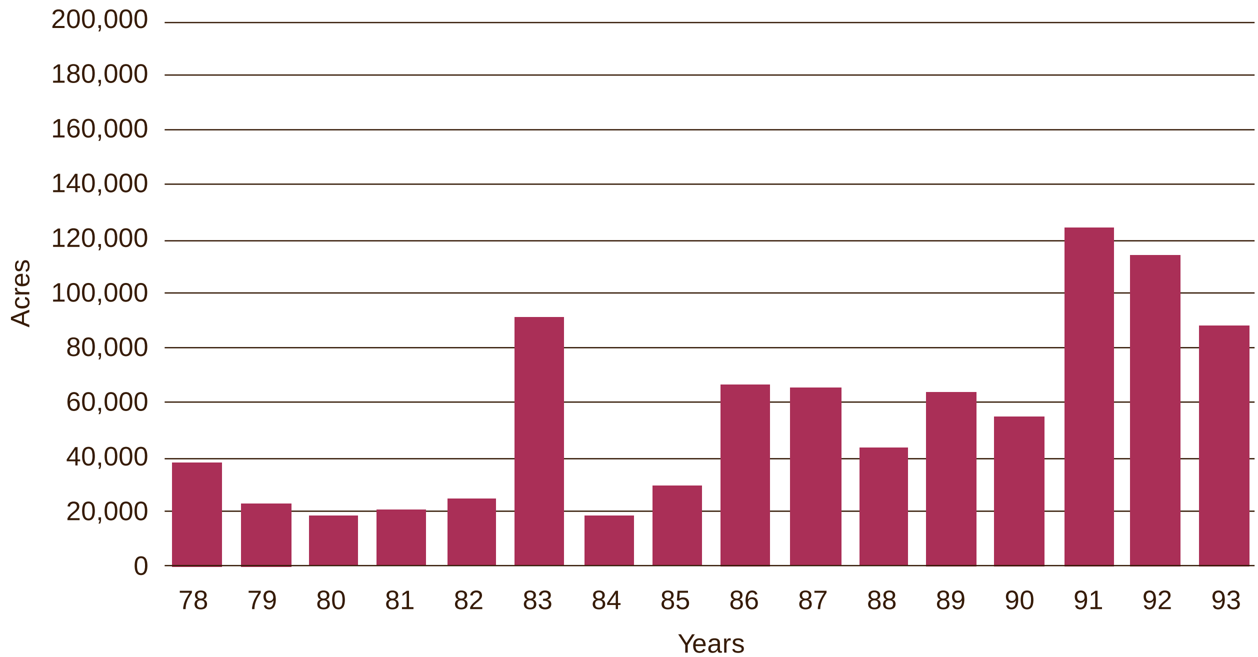
Source: Cal Poly, 1994

along with drainage for Westlands and Tulare subareas. The annual tile drainage yield in 1991 to 1994 ranged from 0.37 to 0.56 af/a for the Grasslands subarea, and from 0.38 to 0.51 af/a for the Tulare subarea. Deep percolation in the Westlands subarea from 1991 to 1994 ranged from 0.30 to 0.47 af/a. These numbers indicate a substantial reduction in deep percolation generally throughout the Valley. In some years, they equal or exceed the SJVDP drainage target of 0.40 af/a. Reduction in irrigation and drainage volumes has come about in part because of water supply reductions during a series of critically dry years and new regulations on drainage and load reduction. Drainage volumes increase during wetter years. Improved regional irrigation efficiencies in the Grasslands area (Figure 4) show the contribution of source control to drainage reduction over time.

Table 3—Westlands Water District Water Management Programs

Programs	Opportunities
Water Measurement	Monitor surface water quality and quantities.
Groundwater Monitoring	Improve water measurement and accounting. Monitor groundwater elevations and quantities.
Shallow Groundwater Monitoring	Monitor quantity and quality of drainage waters. Monitor depth and quality of shallow groundwater.
Water Management Information Program	Improve water measurement and accounting. Provide irrigation scheduling and crop ET information. Monitor surface water quality and quantities. Promote efficient preirrigation techniques. Provide on-farm irrigation system evaluations. Improve on-farm irrigation and drainage systems. Provide educational seminars for staff and farmers. Conduct public information programs.
Communication and Cooperation	Improve communication and cooperative work among districts, farmers, and other agencies.
Pump Efficiency	Evaluate and improve water user pump efficiencies. Evaluate efficiencies of district pumps.
Conjunctive Use	Increase conjunctive use of groundwater and surface water.
Financing Capital Improvements	Facilitate the financing of capital improvements for district and on-farm irrigation systems.
Incentive Pricing	Change the water fee structure in order to provide an incentive for more efficient use of water and drainage reduction.
Salinity Assessment and Monitoring	Monitor soil salinity. Facilitate alternative land uses, where appropriate.
Reservoir Seepage Evaluation	Construct or line regulatory reservoirs.

Figure 5—Land Fallowing in Westlands Water District



Source: Westlands Water District Personal Communications

BWD's source control program has significantly improved irrigation efficiency[1] (from 65 percent in 1988 to more than 80 percent in 1991), drainage water reduction (from approximately 4,800 af in 1986 to 1,000 af in 1992), and subsurface drainage system salt load reduction (from 29,000 metric tons in 1990 to 6,000 metric tons in 1992). See Sidebar on page 19 for information on BWD's source control program.

WWD had only 7,600 acres of tile drained land that discharged to the Drain prior to its closure in 1986 (Johnston, 1996). With no means for drainage water disposal, WWD aggressively implemented source control to reduce drainage water. WWD evaluated water conservation opportunities in terms of technical feasibility, farmer acceptability, costs, and environmental impacts, and developed the programs detailed in Table 3 (WWD, 1993). District farmers are increasingly moving from conventional furrow irrigation to sprinkler/furrow and drip irrigation.

Drought and CVP water allocations reduced water supplies for WWD and contributed to increased land fallowing (Figure 5). WWD implemented water conservation programs that have been effective in reducing deep percolation. At the same time, WWD has sustained productive irrigated agriculture.

High districtwide irrigation efficiency also reflects WWD's water conservation efforts. WWD reported a 17-year average seasonal application efficiency of 83 percent (WWD,

[1] Irrigation efficiency is defined as the percent ratio of crop evapotranspiration plus leaching requirement, minus effective precipitation, to applied irrigation water.

1993). Seasonal application efficiency is the same as irrigation efficiency with the exception of adding farming cultural practices to the numerator:

($SAE = \frac{Et + LR + CP}{AW} \times 100$), where Et is crop evapotranspiration, LR is leaching requirement, CP is farming cultural practices, and AW applied water.)

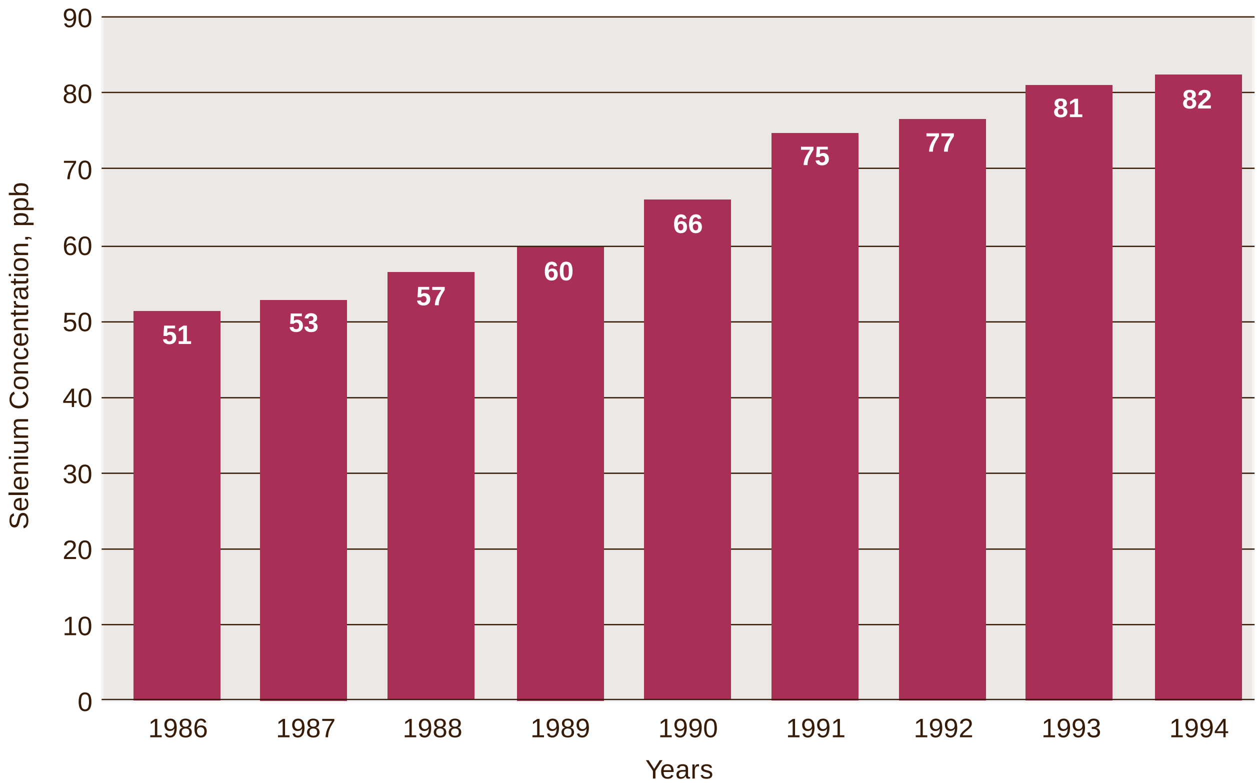
Broadview Water District in the Grasslands subarea is a good example of source control reduction. Its source control program includes:

- tiered water pricing to discourage overirrigation
- district meetings with farmers at the end of the irrigation season to review annual irrigation water deliveries
- water delivery schedule adjustments to facilitate more effective irrigation management
- using SWRCB low-interest loans to purchase sprinkler and gated pipe irrigation systems that improve irrigation efficiencies
- water transfer and purchase assistance to aid farmers in achieving more efficient and economic operations
- participation in improved water management demonstration projects sponsored by DWR and US Department of Agriculture (Cone, 1992)

The WWD 17-year average deep percolation is about 244,000 af/y, averaging 0.48 af/a. The annual deep percolation reported by WWD (shown in Figure 3) varied from a minimum of 0.30 to a maximum of 0.86 af/a. The deep percolation in 1993, a dry year, was 0.31 af/a.

Tulare Lake Drainage District in the Tulare subarea serves 28,078 acres of drained land (TLDD, 1995). The volume of drainage water discharged to evaporation ponds between 1990-94 was 15,584; 10,785; 13,747; 13,553; and 14,741 af/y, respectively. If no tail water is commingled with tile drainage water, the estimates of average drainage yield from 28,078 drained acres between 1990-94 would amount to 0.55; 0.38; 0.48; 0.48; and 0.52 af/a, respectively (Figure 3). These estimates may be compared to the projected 0.40 af/a target for problem water that needs to be collected and managed. In 1991, TLDD met the SJVDP drainage reduction goal of 0.40 af/a by source control.

Figure 6—Selenium Concentration in Grasslands Tile Drainage Water



Source: Central Valley Regional Water Quality Control Board

Unresolved Issues. Improved source control has been necessitated by water shortages due to drought conditions, as well as the need for improved drainage management. Whenever more abundant water supplies are available, tile drainage and deep percolation increase.

Increased irrigation efficiency resulted in increased concentration of selenium in drainage water (Figure 6). In addition, total selenium loads in drainage increased in normal rainfall years following drought years. This could result in failure to achieve water quality standards in discharge areas.

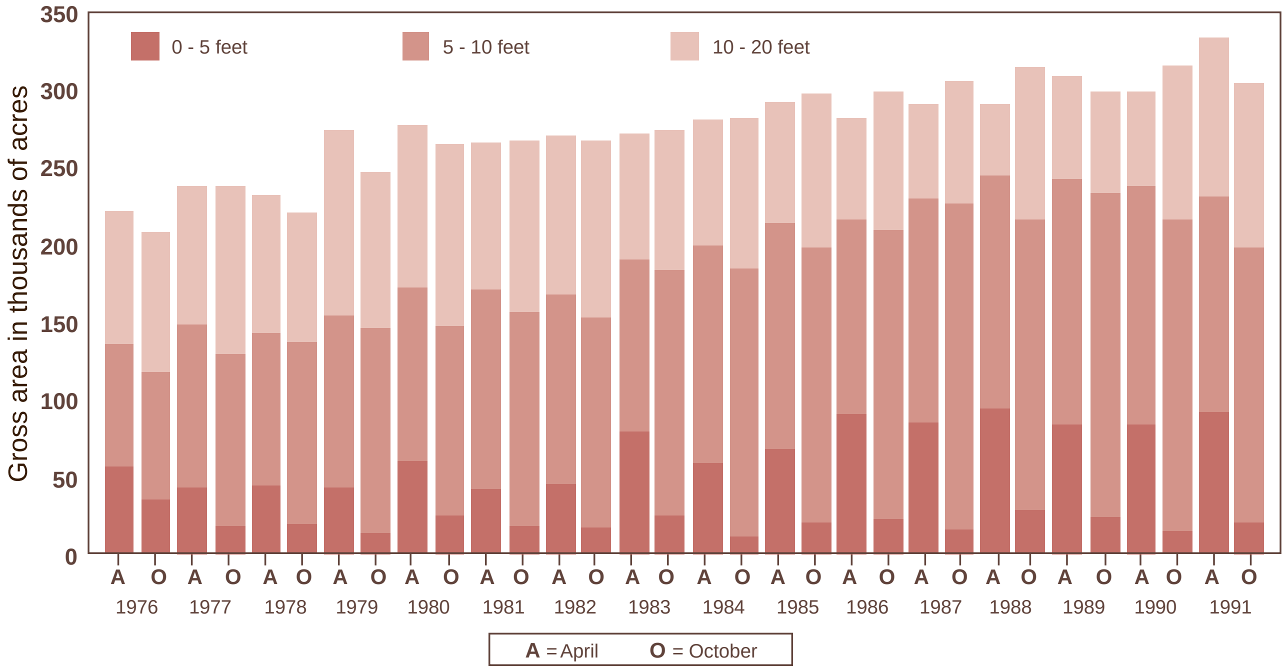
A significant part of BWD's increased irrigation efficiency is from drainage water recycling. But recycling can have adverse impacts of increased

Table 4—Salinity of Delivered Water in Broadview Water District

Year	Average Salinity in ECw, dS/m
1981	3.21
1982	2.89
1983	0.89
1984	0.74
1985	0.65
1986	0.67
1987	0.56
1988	0.87
1989	0.75
1990	1.06
1991	1.25
1992	1.00

salinity of BWD's delivered water supplies (Table 4). Before 1983, when drainage water was recycled because of the lack of an outlet, BWD's delivered water supply was quite saline. Since 1990, in efforts to meet water quality objectives and to stretch available water supplies, increased drainage water recycling again increased salinity in BWD's delivered water supply. A California Polytechnic State University study cited resultant problems such as germination and production problems with salt-sensitive crops (Cal Poly, 1994).

Figure 7—Westlands Water District: Areas of Shallow Groundwater During April and October 1976-1991



Source: Westlands Water District Personal Communications

Although WWD's drainage management efforts have been largely effective in forestalling critical drainage problems, the lack of tile drains and a drainage outlet may be impacting shallow groundwater conditions. According to WWD's annual monitoring, the acreage having shallow groundwater (0-5 foot depth range) increased slightly between 1978 and 1991 (Figure 7).

Districts with tile-drained areas that have severe shallow water table problems have been the primary users of source control practices. Source control practices have not been as strongly promoted in upslope irrigated lands. Drainage water from upslope irrigated lands can contribute to drainage problems in downslope lands.

While source control is reducing drainage volume, other measures must be implemented to manage the remaining drainage beyond SJVDP target levels (0.40 af/a).

Drainage Water Reuse

Drainage reuse is a key element of SJVDP recommendations. Reuse requires installing on-farm tile drains for existing croplands and for salt-tolerant tree and halophyte plantings[2] to enhance evapotranspiration. By 1990, tile drains had been installed on 133,000 acres of Valley farmland. SJVDP projected installing 360,000 acres of tile drains by 2000 – a 170-percent increase. Installation would occur in all subareas, with the largest planned for the Westlands subarea (13.8 times the 1990 acreage) and the Kern subarea (4.8 times the 1990 acreage). Drainage would be treated by 11,900 acres of trees and 10,900 acres of halophytes – a total of 22,800 acres of new plantings.

Several laboratory and field experiments and demonstration projects have been conducted since the mid-1980s to develop information for the reuse concept. DFA, working with other agencies, districts, and growers, was instrumental in developing the reuse component.

Testing and developing drainage reuse systems is progressing. Presently, agroforestry demonstrations focus on irrigation, drainage, salt management, and wildlife protection. Management schemes are being developed for long-term viability of salt-tolerant agroforests, including trees and halophytes. These schemes include: (1) maintenance of soils to ensure growth of trees and halophytes using high salt/boron content drainage water for irrigation; (2) determination of adverse wildlife impacts associated with irrigating agroforestry with drainage water containing selenium and mitigating those impacts; (3) development of agronomic design and management to improve evapotranspiration, growth, and sustainability; and (4) safe disposal or marketing of salts.

Except for small demonstration projects, no tile drains were installed since 1990.

Unresolved Issues. Issues still to be addressed include: (1) developing management schemes for salt-tolerant trees irrigated with saline drainage water while maintaining sustainable soils; (2) avoiding or mitigating potential adverse impacts on birds and wildlife; (3) disposing of accumulated salts; and (4) encouraging installation of tile drains.

Evaporation Systems

Evaporation ponds envisioned by SJVDP bear little resemblance in structure or operation to those that existed in 1990. SJVDP recommendations included the selection, de-

[2] Plants that can grow under extremely saline conditions, such as atriplex or salt bush.

sign, and operation of ponds. Recommended designs were based on DFG criteria, which called for steep interior levee slopes and pond depths that minimize shore bird use. In addition, SJVDP recommended that if selenium concentrations exceeded 2 ppb, alternative safe habitat equal to the evaporation pond area should be provided. If the influent selenium concentration exceeded 50 ppb, accelerated-rate evaporation ponds would be used to reduce required pond areas because traditional ponds would not be feasible in the long run for such conditions.

The plan provides for constructing new evaporation ponds for 2000 and 2040 covering 2,600 acres and 7,600 acres respectively. All ponds would be associated with agroforestry or other drainage reuse systems; some would be solar (lined with black plastic) and some would have accelerated evaporation rates (through overhead sprinklers). A given acre of the new, smaller, evaporation ponds could serve eight to ten times more farmland than in 1990 because of the agroforestry systems.

Evaporation ponds for drainage water disposal have been a major concern to CVRWQCB because of wildlife impacts. In August 1993, CVRWQCB adopted Waste Discharge Requirements for operating evaporation ponds. Pond operators, for a significant acreage of existing ponds, said they would cease operation. By 1995, the active pond area under the prescribed Waste Discharge Requirements was 5,444 acres, compared to 6,700 acres of total pond area in the Tulare and Kern Subareas in the late 1980s.

Waste Discharge Requirements define requirements and compliance schedules designed to discourage wildlife use of evaporation ponds or provide mitigation and compensation measures to offset the adverse effects of evaporation ponds. As a result, much has been done in the design, construction, and operation of ponds to discourage wildlife use. CVRWQCB used the above-mentioned DFG criteria to set waste discharge requirements that would reduce wildlife use of ponds by steepening interior pond slopes and removing levee windbreaks constructed to reduce wave action and levee erosion. In addition to modifying pond construction, improved water distribution and water control structures are required to maintain deeper water levels that reduce bird feeding habitat.

Table 5 compares SJVDP recommendations with CVRWQCB requirements for existing evaporation ponds. CVRWQCB did not follow SJVDP's recommendations that required alternative habitat equal to evaporation pond area where influent selenium concentration exceeds 2 ppb. Considerable controversy and debate have centered on this issue. Dischargers contended that the recommendation was based on inadequate

Table 5—Evaporation Basin Mitigation/Compensation Habitat

					USFWS Protocol		Consensus Agreement		
Evaporation Basin Operators	Pond Size	Se (ppb)	SJVDP Recommendation	CVRWQCB WDR Compensation Habitat	USFWS Alternative Habitat	USFWS Compensation Habitat	Alternative Habitat	Compensation Habitat	Demonstration Habitat
	(acres)			(acres)	(acres)	(acres)	(acres)	(acres)	(acres)
Rainbow Ranches	100	430	C	100	89	13	no agreement		
Lost Hill Water District	542	211	C	0 *	2,389	113	no agreement		
ALPAUGH GROUP				40	17	14	closed		
1. Morris & Sons	35	33	B		4	5	closed		
2. Steve/Wayne Martin	13	33	B		2	2	closed		
3. Bowman Farms	15	18	B		7	2	closed		
4. 4 J Corporation	25	39	B		4	2	closed		
5. Pryse Farms	80	14	B		0	3	closed		
DLM Partners (Britz, Inc.)	25	52	C	0	26	3	8	3	15
Tulare Lake:				207 $	2,537	320	no agreement		XX
North	301	1.8	A		0	5			
Hacienda	1,026	14	B		570	106			
South	1,831	13	B		1,967	209			
Stone Land Company	210	2.3	B	0	0	0	not required		
Westlake Farms:				80 X	110	41	57	41	640
North	260	1.5	A		0	4			
South	740	7.1	B		110	37			
G & C Meyer	59	0.8	A	0	0	1	not required		
LDS Church	90	NA	ND	0	ND	0	closed		
Acme Drainage	95	1.3	A	0	ND	ND	closed		
TOTAL ACRES	5,444			427	5,168	505	65	44	655
TOTAL ACTIVE ACRES	5,094								

A No alternative habitat required
B Alternate habitat:pond ratio equal to 1:1
C Use accelerated rate evaporation pond
* providing water=drainage inflow to Westlake
X also 640 acres of demonstration wetlands

XX proposed to have 1,000 acres of demonstration project
$ 320 acres of compensation habitat constructed
NA Not available
ND No data

research and providing the volume of fresh water required for alternative habitat recommended in the 1990 *Plan* would be excessively costly and difficult to implement in the water-short Valley. Dischargers, wildlife interests, and government agencies have negotiated and cooperated in implementing projects and developing information on appropriate mitigation habitat requirements.

USFWS and several public interest groups filed an appeal with SWRCB in 1993, asserting that CVRWQCB's Waste Discharge Requirements were inadequate to protect wildlife using evaporation ponds. SWRCB held an evidentiary hearing in 1995. Meanwhile, USFWS developed alternative and compensation habitat protocols based on the concentration of selenium in waterfowl eggs (USFWS, 1995a, 1995b). Determination of habitats would consider egg selenium content and other factors, rather than only selenium concentration in pond water as suggested by SJVDP. Several pond operators and other parties involved in the appeal signed a consensus agreement to follow USFWS protocols. Table 5 compares the evaporation pond acreage, alternative or compensatory habitats recommended by SJVDP and required by CVRWQCB, USFWS protocols, and the consensus agreement.

SWRCB released *Petitions Regarding Tulare Lake Evaporation Ponds – Staff Technical Report* (SWRCB, 1996) and agreed with the petitioners that the final EIRs for evaporation ponds inadequately address (1) impacts of trace elements other than selenium on birds, (2) negative effects of salinity levels on birds, and (3) impacts of pond closures. In addition, four of the final EIRs inadequately address sublethal impacts on birds from exposure to selenium. On March 21, 1996, SWRCB passed a resolution remanding the Waste Discharge Requirements and EIRs of six Tulare and Kern subarea drainers (TLDD; Lost Hills Water District; Rainbow Ranches, Inc.; G&C Meyer Farms, Inc.; Stone Land Co.; and Morris & Sons Farms) to CVRWQCB for reconsideration.

As of July 1996, Morris & Sons Farms ceased pond operation and LHWD initiated proceedings for phased closure of its ponds. Of the six operators who previously reached agreement with USFWS on continued pond operation, four from the Alpaugh Group (Martin Ranch, Bowman Farms, 4J Corp., and Pryse Farms) decided to cease pond operations. Of all drainers in the Tulare Lake subarea, only Britz, Inc. and Westlake Farms have reached agreement with USFWS and continue pond operation. Of those who have not reached agreement with USFWS, only TLDD, Rainbow Ranches, G&C Meyer Farms, and Stone Land Co. still intend to continue pond operation. Of 14 pond operators in 1993 (SWRCB, 1996), only 6 intend to continue operation. At present, 7 drainers are operating 5,094 acres of evaporation ponds, including LHWD, which is planning for phased pond closure.

Modified Evaporation Systems. There has been no significant effort to develop accelerated rate evaporation systems as suggested in the 1990 *Plan*. SJVDP did not recommend a specific system, but suggested that evaporation pond areas could be reduced substantially by lifting and dripping drainage water from elevated perforated water pipes to accelerate evaporation. The Bureau conducted a demonstration project with such a system in El Paso, Texas, but the project was not a comparable application. Such a system has not been used in the Valley, because lifting the water the required height to ensure adequate evaporation would be energy intensive and installing, maintaining, and operating the system would be costly. Moreover, confining wind-blown sprays would be difficult because of Valley winds.

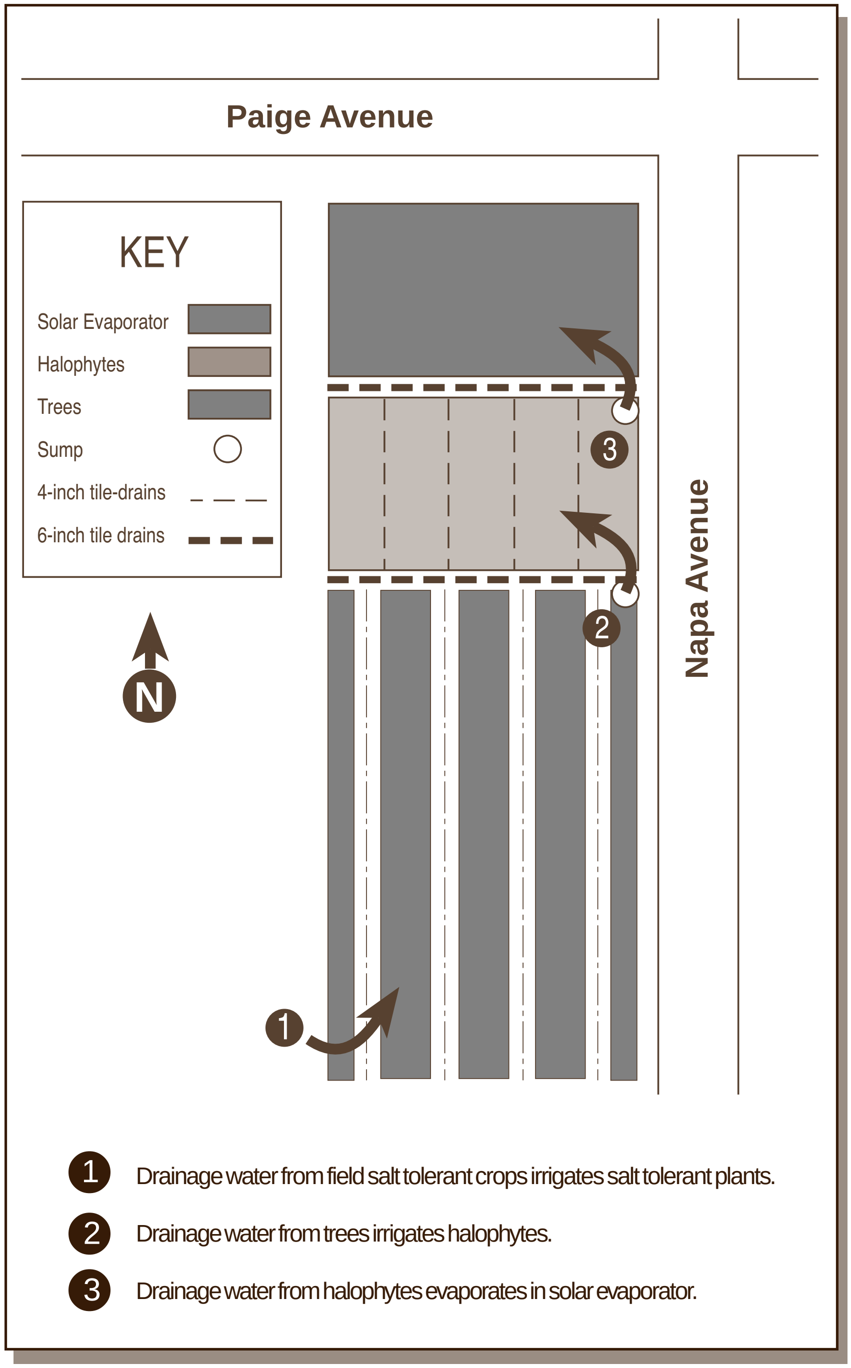
DFA promotes using a "solar evaporator" at the Red Rock Ranch and Mendota agroforestry demonstration projects (Figure 8). Drainage water is evaporated in a shallow 2-acre depression lined with plastic. Sprinklers apply a thin film of water during each application to reduce ponding and wildlife impacts. This system was modified in 1996 in response to notices of Waste Discharge Permit violations issued by CVRWQCB for the Red Rock Ranch and Mendota agroforestry projects. The violations were for an approximately 2-inch depth of ponding sufficient to grow brine flies and attract nesting birds. USFWS examined eggs laid in the nests, finding that they contained dead and deformed embryos with extremely high concentrations of selenium. Modification to the sprinkler application rate has now eliminated ponding in the solar evaporators.

Advances in Evaporation Pond Design and Operation. TLDD and Westlake Farms are major evaporation pond operators; both have made notable progress in addressing evaporation pond problems.

TLDD, pursuant to its Waste Discharge Requirements, modified about 117,000 lineal feet or about 48 percent of the interior slopes of its Hacienda and South Basins to 3:1 slopes (Davis, 1995). Modifications were not required at TLDD's North Basin. In addition, TLDD installed distribution and control structures at its ponds to maintain required minimum water depths of 2 feet, except while draining and filling. Tires used for pond levee stabilization have been removed. Conventional hazing has been practiced; hazing using a hover craft has been tested with promising effectiveness (Davis, 1995).

CVRWQCB's remanded Waste Discharge Requirements for TLDD required 207 acres of compensation wetland habitat, and TLDD constructed about 320 acres (TLDD, 1995). The habitat has 37 islands and more than 80 miles of shoreline. The aim is to make 45 miles of evaporation pond levees unattractive to waterfowl while compensating

Figure 8—Red Rock Ranch Agroforestry Demonstration Project



Source: Department of Food and Agriculture with 80 miles of suitable nesting and foraging habitat for shorebirds.

According to TLDD, analyses of egg samples collected in June 1994 found no deformities in samples of 9 eggs from the North Basin, 8 eggs from the Hacienda Basin, and 18 eggs from the South Basin. Nest counts at Hacienda and South Basins have also shown encouraging results. Nesting at these basins has declined, whereas the 320-acre compensation habitat had 2,167 nests in 1995.

Westlake Farms also initiated an aggressive program of windbreak removal and evaporation pond modification in compliance with its Waste Discharge Requirements. This program includes steepening side slopes and stabilizing them with plastic sheets (Howe, 1995). These efforts have significantly deterred shorebird use. No shorebirds were observed at Westlake's 20-acre experimental modified pond from late June 1993 through early April 1994 (H.T. Harvey & Associates, 1994).

In addition, Westlake completed its 130-acre alternative wetland habitat in November 1993. In 1994, the alternative habitat attracted an average of 3,741 birds from March through June as compared to 3,965 birds at Westlake's ponds. The number of birds per acre of habitat during the 1994 March through June breeding season, however, was three to seven times higher than at the evaporation ponds. In 1994, 295 nesting attempts were recorded at the alternative habitat site, whereas 46 and 9 nesting attempts were recorded in the North and South Basins, respectively. In contrast, USFWS recorded 436 nesting attempts at the South Basin in 1993; 565 were recorded by H.T. Harvey in 1995. (H.T. Harvey & Associates, 1996)

Westlake also participated with the Bureau, USFWS, DWR, and DFG in a 640-acre demonstration wetland project. In March 1994, the first phase (2 cells covering about 145 acres) of the project was completed. In June 1994, one cell produced 87 nesting attempts, while the entire 640-acre section had about 340 nesting attempts.

USFWS monitored the reproductive performance of stilts and avocets at the demonstration project site in the 1994 and 1995 breeding seasons, concluding that the project initially attracted breeding shorebirds (Skorupa, 1995). In 1994, about 390 nesting attempts were made at the two cells. In the southwestern-most cell (G), birds attempted two nests per acre compared to 0.8 at traditional evaporation ponds without islands. In 1995, cell G was not flooded and, thus, had no shorebird nesting attempts. In addition, the other cell (F) had almost no shorebird nesting attempts because cattail growth engulfed most of the islands. However, the cattails attracted and successfully supported a breeding colony of tricolored blackbirds – a species of special concern.

In 1994, 55 percent of all stilt and avocet nesting attempts were successful. Nest predation by racoons and coyotes caused the most nesting failures. In 1995, 61 percent of stilt and avocet nesting attempts were successful with nest flooding causing the largest numbers of failures. Hatchability of full-term stilt and avocet eggs has been statistically consistent with the background value of 96.2 percent at other selenium-normal locations in the Valley. At the time of reporting, only one teratogenic embryo was detected among 1,197 full-term stilt and avocet eggs monitored at the demonstration project. The background rate of teratogenesis was estimated at 1 per 1,000 embryos, compared to 100 to 500 per 1,000 embryos documented in the past at the most contaminated Tulare Basin evaporation ponds.

Unresolved Issues. SJVDP's 1990 *Plan* envisioned modified evaporation ponds as components of drainage reuse systems that have not yet been widely implemented. Closing of some evaporation ponds could damage long-term Tulare Basin agriculture. The short supply of suitable water for wetland habitat and costs of monitoring, establishing, and operating mitigation habitat remain major problems.

Demonstrations on accelerated-rate evaporation systems have not yet been conducted as recommended by SJVDP. Environmental requirements, energy demand, and cost appear to be major constraints.

Land Retirement

Currently, only the federal government has a land retirement program. CVPIA authorized the Bureau to initiate a voluntary land retirement program in 1993; the program is ongoing. In 1992, SB 1669, the San Joaquin Valley Drainage Relief Act, authorized DWR to undertake a land retirement program. However, appropriated funds have recently been withdrawn.

SJVDP projected retirement of 21,100 acres by 2000, with 18,000 acres of that total in the Westlands subarea. Land eligible for retirement would have combinations of high selenium concentrations in shallow groundwater, low productivity, and drainage problems. CVPIA land retirement goals include retiring lands to reduce drainage, conserve water, and make water available for wildlife habitat, thereby contributing to fish and wildlife restoration goals.

In 1994, DWR and the Bureau hosted several public workshops in the Valley, Sacramento, and San Francisco Bay area. Those workshops explored the level of interest among landowners and the concerns of environmental organizations, local water suppliers, and drainage interests. The Bureau then developed *Draft Interim Procedures and*

Guidelines in consultation with DWR staff. The *Guidelines* addressed coordination between State and federal programs, procedures for soliciting lands eligible for retirement, a process for selecting lands for retirement, the role of local water districts in setting priorities for retirement, interests that might be acquired, and postretirement management.

In 1996, approximately $1 million of CVPIA funds were used to acquire approximately 640 acres of irrigated land in WWD, near the Mendota Wildlife Management Area. Included in the purchase was approximately 677 af of water associated with the parcel. DFG is preparing a management plan emphasizing upland game species.

The Bureau initiated its land retirement program by soliciting willing sellers to submit offers of land for retirement. The Bureau has received letters from landowners interested in selling their drainage-impaired lands. Wildlife interests want to restore habitat that would result in nodes of habitat and corridor links between native habitats to the west and the River, like the Mendota Wildlife Management Area.

Unresolved Issues. Because land retirement is controversial and complex, implementation is proceeding slowly. Disposition of water rights for retired lands is unresolved. Water agencies serving those lands prefer that any water conserved from retirement remain in their district service areas. They may, therefore, start their own land retirement efforts. Environmental interests are concerned that if land is retired, the water should not be used in a way to transfer the drainage problem from the retired land to another part of the Valley. They want reductions in contaminants entering the River and no toxic trace element exposure to the public or wildlife. Managing retired lands, and possible impacts to neighboring lands and continuing agricultural operations, are unresolved problems. In local workshops, some local landowners have expressed unwillingness to participate in land retirement programs. Others were willing to implement programs combined with other measures to solve drainage problems, provided the conserved water remains in the district. Depending on local conditions, land retirement could be done selectively without causing secondary impacts. Land retirement may impact local economies, but the extent of the effects could depend on alternative land uses.

Groundwater Management

SJVDP projected that by 2000, groundwater pumping in suitable aquifers above the Corcoran Clay would allow for deep percolation of an additional 0.4 af/a of problem water on 40,000 acres of farmland in the Grasslands, Westlands, and Tulare subareas. This new, relatively shallow, groundwater pumping would lower root-zone water tables. This groundwater pumping would occur in addition to ongoing deeper groundwater pumping, mostly from below the Corcoran Clay. WWD investigated the feasibility of implementing this concept in the Panoche Fan (Ken Swanson, Personal Communication, WWD, 1996). Groundwater quality was unacceptable with more than 1,250 ppm total dissolved solids. Blending groundwater with California Aqueduct water was also infeasible and the project terminated. At present, shallow groundwater management to reduce problem water has not been implemented anywhere in the SJVDP area.

Unresolved Issues. The groundwater management concept has not been implemented and should not be until additional factors are studied. These factors are: (1) locating aquifers in the semiconfined zone having suitable quality water for irrigation and/or wildlife habitat use; (2) determining the cost of high-density wells that would extract water from the low-water-yielding semiconfined zone; and (3) resolving the possible incompatibility with SWRCB's nondegradation policy. Degradation of the semiconfined zone threatens the long-term quality of critical water supplies underlying the Corcoran Clay, which is subject to significant leakage.

Growers expressed strong reservations in recent local workshops about the effectiveness of groundwater management as a drainage reduction method. They cited poor-quality shallow groundwater, discontinuity in Corcoran Clay layers, degradation of deeper groundwater aquifers, subsidence, degradation of soil quality from increased salinity, and difficulty of implementation as factors.

Discharge to the San Joaquin River

About 50,000 acres of irrigated lands in the Grasslands area currently have tile drains. In the past, subsurface drainage water from these farmlands (73,000 af in 1987 and 24,000 af in 1992) was discharged through the Grasslands wetlands and wildlife areas to the San Joaquin River. Alternating agricultural drainage and freshwater flows in the channels and Mud and Salt Sloughs tried to provide water to the wetlands and wildlife areas, avoiding flows with higher concentrations of selenium; however, this system was inefficient and wasted water.

SJVDP recommended reopening a portion of the San Luis Drain and extending it to the San Joaquin River below the confluence with the Merced River. Selenium-contaminated sediment within the Drain would be removed and disposed of in Kesterson Reservoir. Relatively poor-quality drainage from tile-drained areas would then be discharged to the Drain and the San Joaquin River, bypassing the Grasslands wetlands and wildlife areas. The quantity of drainage discharge to the River would be

SJVDIP participating agencies promote and support drainage water reuse demonstration projects.

- **USBR, through its Challenge Grant Program, funds the following projects:**

  — WRCD's demonstration project to reuse and reduce drainage water and to model salt and selenium balance in a reuse system

  — TLDD's project to demonstrate water application practices to establish and sustain salt-tolerant plants in clay soils

  — WRCD's project on 640 acres of Red Rock Ranch to integrate farm cropping with on-site reuse of drainage water and on-farm management of salts and selenium

- **DWR funds the following demonstration projects:**

  — experimental sequential reuse project to test the long-term maintenance of salt and water balance by irrigating salt-tolerant eucalyptus trees and halophytes with saline drainage water

  — investigation of how wildlife is impacted by drainage water reuse projects

  — participation with TLDD to evaluate the concept of using eucalyptus trees and halophytes with evaporation ponds

- **DFA and USNRCS provide the following technical assistance:**

  — select, plant, and evaluate superior salt-tolerant trees and halophytes

  — conduct experimental project in Mendota to evaluate operation and effectiveness of salt-tolerant eucalyptus trees and halophytes

  — conduct experimental project with solar evaporators at Red Rock Ranch (see Figure 8)

  — use salt-tolerant trees to intercept and lower shallow water tables

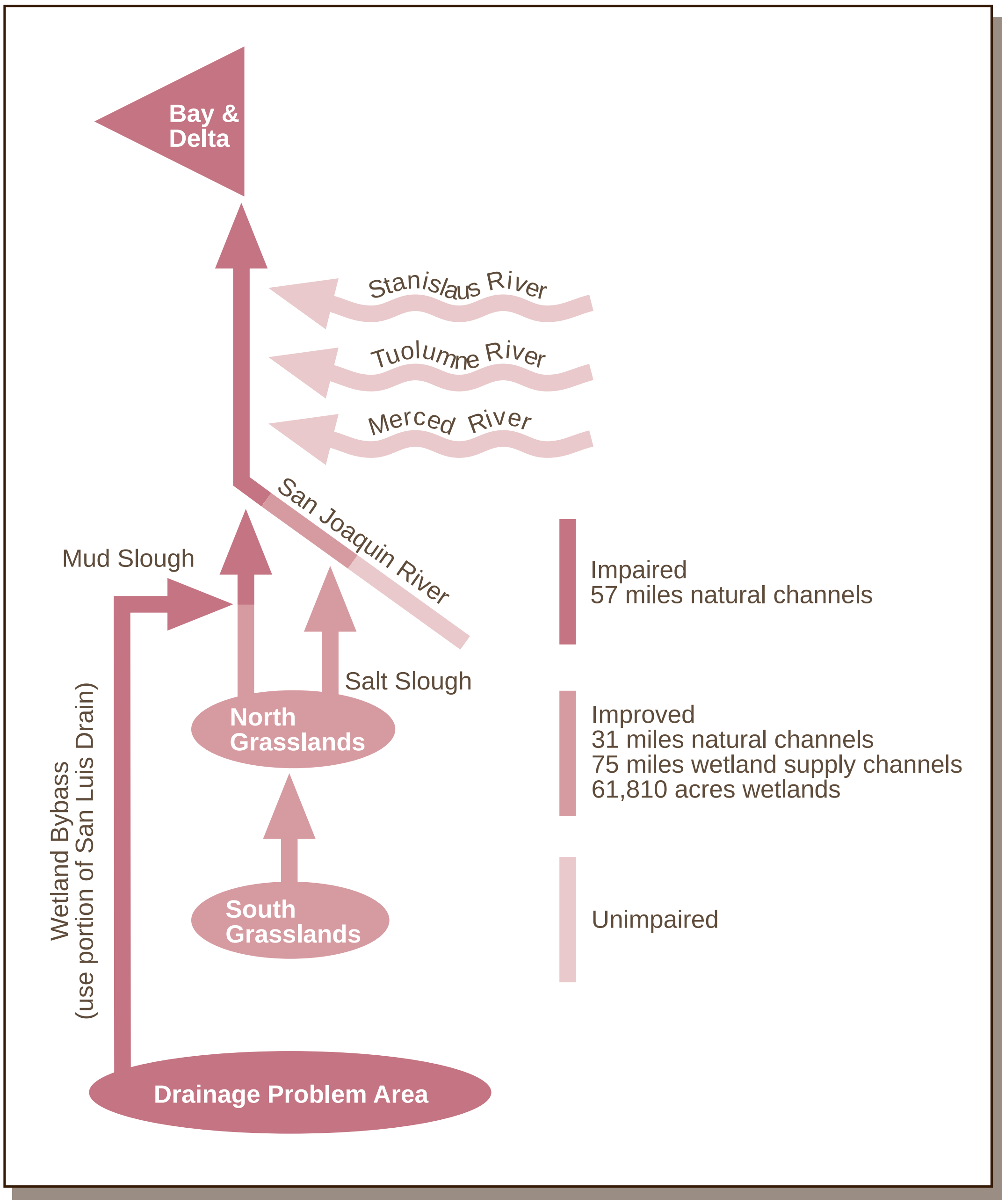
  — hold annual agroforestry workshops

  — administer studies on economic values and returns from drainage reuse products (e.g., halophyte livestock feed, agroforest biomass, etc.)

10,700 af from 26,800 acres by 2000 and 21,000 af from 52,300 acres by 2040. The remaining drainage water from the area would be used in wetlands and wildlife areas or reused. Drainage water would only be discharged to the River or wetlands if CVRWQCB water quality objectives were met.

Grasslands drainers have formed a drainage entity called Grassland Area Farmers by signing an agreement with the San Luis & Delta-Mendota Water Authority. The Water Authority, in turn, has an agreement (Grasslands Bypass Channel Use Agreement)

Figure 9—Lower San Joaquin River After Implementation of Grasslands Bypass Channel

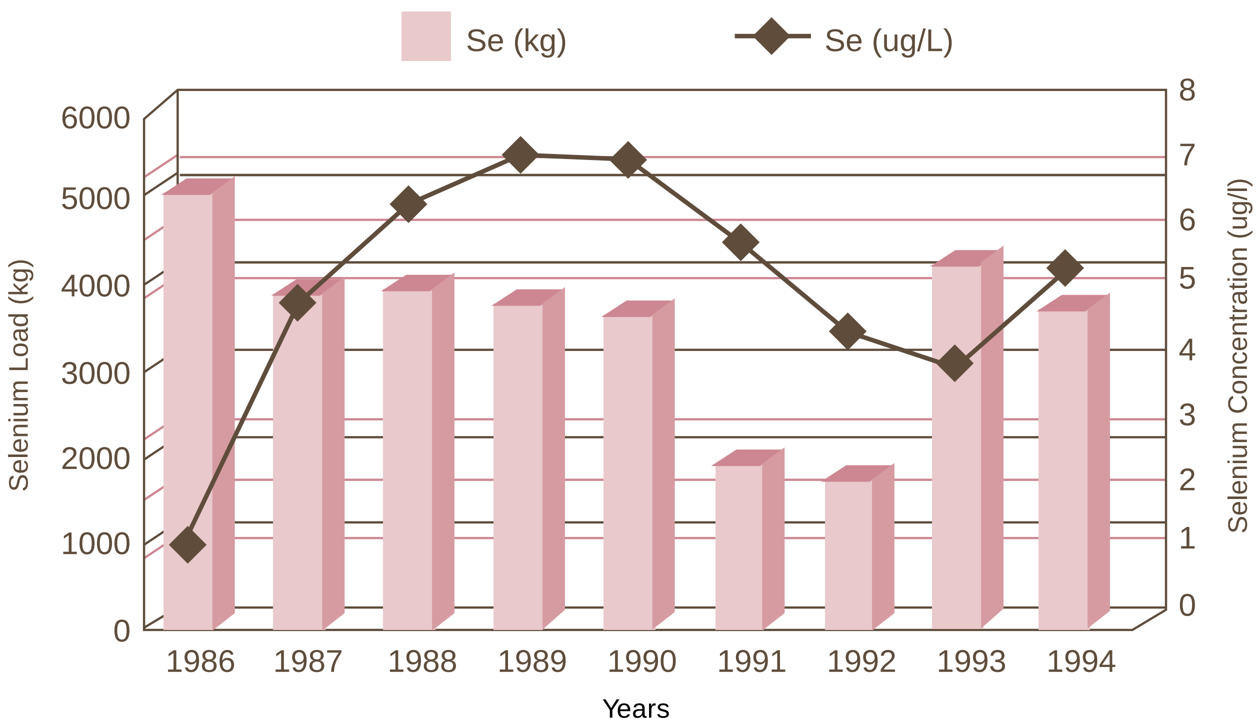


Source: CVRWQCB

with the Bureau to use a portion of the Drain to bypass wetlands in the Grasslands area and discharge drainage to North Mud Slough. The Agreement is a limited-term contract to use the Drain. The Agreement describes a five-year plan and commitment to reduce annual selenium loads to the River. The initial two-year selenium annual load target is 6,660 pounds, and the annual load would decrease in five years to 5,661 pounds – 85 percent of the nine-year average (USBR, 1995).

The Grasslands Bypass Channel project will improve water quality in Grasslands water supply channels, Salt Slough, and a portion of Mud Slough (Figure 9). This project is similar to SJVDP's concept to use part of the Drain to bypass area wetlands, the difference being that SJVDP recommended extending the Drain to the San Joaquin River

Figure 10—Average Annual Selenium Concentrations and Loads at Crows Landing Bridge Site: Water Years 86-94



Source: CWRWQCB

below its confluence with the Merced River, while the project connects the existing Drain to North Mud Slough.

CVRWQCB has a water quality control plan for the San Joaquin River basin, which is essentially the Grasslands subarea as defined by SJVDP. The plan largely focuses on regulating agricultural drainage in the basin. The drainage management implementation plan adopted in 1988 (CVRWQCB, 1988) focused on voluntary drainage volume

Table 6—Summary of Selenium Water Quality Objectives and Compliance Time Schedule for the San Joaquin River

Water Body/ Year Type	October 1, 1996	October 1, 2002	October 1, 2005	October 1, 2010
Salt Slough and Wetland Water Supply Channels	**2 ug/L monthly mean**			
San Joaquin River below the Merced River; Above Normal and Wet Water Year*		*5 ug/L monthly mean*	**5 ug/L 4-day average**	
San Joaquin River below the Merced River; Critical, Dry, and Below Normal Water Year		*8 ug/L monthly mean*	*5 ug/L monthly mean*	**5 ug/L 4-day average**
San Joaquin River above the Merced River and Mud Slough (north)				**5 ug/L 4-day average**

Selenium Water Quality Objectives and *Performance Goals*
Water Quality Objectives are the levels of water quality constituents established by SWRCB and USEPA for the reasonable protection of beneficial uses of water. Performance Goals are a scheduled compliance with Water Quality Objectives and are used to measure progress towards their achievement.
** The water year classification will be established using the best available estimates of the 60-20-20 San Joaquin Valley water year hydrologic classification at the 75 percent exceedance level (DWR Bulletin 120). The previous year's classification will apply until an estimate is made of the current water year.*
Source: CVRWQCB

and pollutant load reductions through on-farm best management practices – mainly water conservation. CVRWQCB monitored progress toward meeting water quality objectives by established compliance dates. Waste Discharge Requirements were to be considered if water quality objectives were not met. CVRWQCB also prohibited activities such as installing more subsurface drains that would have increased the discharge of poor-quality drainage water.

Because the objectives of the 1988 basin plan were not achieved, CVRWQCB completed and adopted an amendment to the basin plan (May 3, 1996), conceptually including both the Bypass Channel and SJVDP proposal to extend the Drain and establish water quality objectives. SJVDP's recommended Drain extension is subject to achieving CVRWQCB water quality objectives; yet mandated compliance with objectives by 2010 may require extending the Drain to the River. CVRWQCB is primarily concerned about selenium because of fish and wildlife water uses in the basin. Table 6 shows the selenium water quality objectives and compliance dates (CVRWQCB, 1996).

From 1989 to 1992, CVRWQCB's drainage monitoring results showed reductions of 45 to 65 percent in selenium, boron, and salt loads. In WY 1993, the calculated loads of selenium, boron, and salt in the River increased to the highest levels since WY 1986 (CVRWQCB, January 1995). Figure 10 shows selenium loads and flow-weighted selenium concentrations for the River at Crows Landing. From WY 1986 to 1989, the flow-weighted selenium concentration (selenium concentration times flow divided by total flow) in the drains entering the Grasslands subarea increased. Selenium load in the drains, however, showed a marked decrease from WY 1987 to 1992.

The Grasslands subarea 1992 water allocation was the lowest in the six-year period. The selenium load per irrigated acre varied from 0.16 pounds in 1987 to 0.07 in 1992. Both a drought-induced decline in irrigated acreage and improvements in water management contributed to reducing the drainage selenium load. In 1993, a wet year, federal water allotments to growers increased, and the selenium load more than doubled. In 1994, a dry year with reduced federal water allotments, the selenium load decreased slightly from 1993, while the concentration increased.

CVRWQCB estimated the maximum annual selenium loads in pounds and monthly percentage change in selenium loads for various water year types required to meet selenium water quality objectives (CVRWQCB, 1996). Compliance with selenium objectives will be difficult to attain; data indicate that stringent drainage management and other control measures will be required to meet water quality objectives. The responsibility for meeting objectives will be shared by all those generating drainage water. Grasslands basin drainers have initiated a regional management plan to achieve water quality objectives in the River (Grasslands Basin Drainers, 1995).

Unresolved Issues. 1990 *Plan* for the Grasslands subarea recommended source control, drainage reuse, land retirement, evaporation pond, groundwater management, and discharge to the San Joaquin River. The discharge to the River was subject to meeting CVRWQCB water quality objectives. Source control has been practiced extensively in the grassland area. Other SJVDP recommended measures for this area have not been implemented. Source control alone is not sufficient to meet water quality objectives in the River and Mud Slough. The plan to extend the Drain to the River downstream of the Merced River confluence, as proposed by SJVDP, has yet to be developed.

Protection and Restoration of Fish and Wildlife Habitat

SJVDP proposed several water management actions to improve the volume and quality of water supporting fish and wildlife habitat. Grasslands wetlands would receive 129,000 af of adequate-quality water, including 74,000 af from the CVP Delta-Mendota Canal (after construction of necessary delivery facilities), and 55,000 af of tail water or runoff from agricultural lands. By 2000, 38,600 af of adequate-quality subsurface drainage water would be provided to wetlands. All drainage from the Panoche Water and Drainage Districts would be conveyed in the Drain, bypassing area wetlands.

CVPIA was approved in 1992 (Title 34, PL 102-575), directing the U.S. Department of the Interior to provide Level II water supplies immediately to federal, State, and private wildlife refuges. Eventually, 800,000 af of CVP water will be set aside for fish and wildlife benefits. In the Grasslands subarea, this would provide the substitute water supplies that SJVDP recommended. In addition, incremental annual increases of 10 percent will be provided until all the refuges receive full development water supplies no later than 2002. In 1993 and 1994, the Bureau delivered 130,000 af and 168,000 af, respectively, to San Joaquin Valley refuges. The SJVDP recommendation has, therefore, been implemented since 1993. The Bureau is also preparing to provide facilities (in accordance with SJVDP recommendations), such as Delta-Mendota Canal turnouts, to deliver substitute water.

Unresolved Issues. Additional long-term conveyance facilities must be constructed and long-term contracts for refuge water supply must be established.

Institutional Changes

SJVDP recommended tiered water pricing, improved water delivery scheduling, water transfers and marketing, and formation of regional drainage management organizations as institutional components to implement drainage management more effectively.

Tiered Water Pricing. BWD, located near Firebaugh in the Grasslands subarea, has 7,500 acres of subsurface drainage systems that have discharged drain water to the River since 1983. BWD initiated a tiered water-pricing program for irrigation water in 1989 to promote improving farm-level water management practices and reduce the volume of water collected in subsurface drainage systems (Wichelns, 1992). BWD chose a tiered water-pricing structure rather than a uniform increase in water prices to motivate farmers who used excessive amounts of irrigation water, while not penalizing farmers who already implemented appropriate management practices. Tiered water pricing was implemented to provide farmers with a significant economic incentive.

Although it is impossible to completely separate the effects of tiered water pricing

Table 7—Summary Statistics Describing Irrigation Depths on Cotton in Broadview Water District, 1986 through 1993

	1986	1987	1988	1989	Four Years 1986-1989
	(Equivalent Depth, In Feet)				
Observations	(29)	(25)	(26)	(32)	(112)
Mean	3.25	3.22	3.31	3.34	3.28
Standard Deviation	0.39	0.48	0.46	0.55	0.48
Minimum	2.44	2.46	2.45	2.00	2.00
Maximum	3.88	4.87	4.28	4.41	4.87

	1990	1991	1992	1993	Four Years 1990-1993
	(Equivalent Depth, In Feet)				
Observations	(33)	(30)	(21)	(38)	(122)
Mean	2.84	2.46	2.25	2.24	**2.46
Standard Deviation	0.46	0.26	0.31	0.34	0.43
Minimum	2.07	1.90	1.68	1.73	1.68
Maximum	3.94	2.97	2.85	2.98	3.94

NOTE: The number of observations in each year is included in parentheses. A double asterisk denotes that the mean irrigation depth for 1990 through 1993 is significantly less than the mean irrigation depth for 1986 through 1989, at p=0.01.

Source: Cone and Wichelns, 1994

from the effects of drought conditions and reduced water supply, improved water management practices and irrigation technology in BWD from 1989 through 1994 indicate that progress can be achieved through economic incentive programs. Farmers have been free to choose the combination of management and technology changes that are most appropriate to their farming operation. This has allowed impressive water delivery and drain water volume reductions in BWD while still maintaining or slightly increasing crop yields.

BWD decided that the unit price of water should be increased substantially when water deliveries to any crop exceeded 90 percent of the average irrigation depth observed for that crop from 1986 through 1988. Before BWD implemented the tiered water-pricing program, the unit price of water was $16 per af, regardless of the volume used. A

Table 8—Summary Statistics Describing Irrigation Depths on Selected Major Crops in Broadview Water District, 1986 through 1993

1986 through 1989	Tomatoes	Cantaloupes	Alfalfa Seed	Grain
	(Equivalent Depth, In Feet)			
Observations	(20)	(32)	(16)	(29)
Mean	3.04	2.01	2.01	2.50
Standard Deviation	0.63	0.46	0.65	0.84
Minimum	1.85	1.17	0.70	1.19
Maximum	4.61	3.07	3.62	4.61

1990 through 1993	Tomatoes	Cantaloupes	Alfalfa Seed	Grain
	(Equivalent Depth, In Feet)			
Observations	(27)	(17)	(18)	(17)
Mean	*2.78	*1.81	**1.39	**1.78
Standard Deviation	0.57	0.37	0.53	0.74
Minimum	1.92	1.31	0.65	0.79
Maximum	4.23	2.46	2.51	3.10

NOTE: The number of observations for each crop, in each year, is included in parentheses. The mean irrigation depths for 1990 through 1993 are significantly less than the mean irrigation depths for 1986 through 1989, at p=0.01 (**), and at p=0.10 (*).

Source: Cone and Wichelns, 1994

dual pricing system was selected for the tiered-pricing scheme to minimize potential confusion. The $16 per af price was retained for any water deliveries up to the crop-specific level for any field. The price of water delivered exceeding the tiered level was set at $40 per af. The $24 price increase was determined by estimating the total cost of collecting and discharging subsurface drain water in BWD and dividing that cost by the volume of water that likely would be delivered in excess of crop-specific tiering levels.

The average irrigation depths for cotton and other major crops in BWD during 1986 through 1989 are given in Tables 7 and 8. While these depths are typical for surface irrigation methods in arid regions, a maximum and minimum range of changes in irrigation depths (more than 2 feet for cotton and tomatoes) for different fields was

Table 9—Summary Statistics Describing Subsurface Drain Water Depths for Farm-Level Drainage Systems in the Broadview Water District 1986 through 1993

	1986	1987	1988	1989	Four Years 1986-1989
	(Equivalent Depth, In Feet)				
Observations	(22)	(22)	(22)	(22)	(88)
Mean	0.71	0.60	0.54	0.52	0.59
Standard Deviation	0.37	0.30	0.30	0.23	0.31
Minimum	0.08	0.15	0.15	0.13	0.08
Maximum	1.37	1.27	1.29	1.01	1.37

	1990	1991	1992	1993	Four Years 1990-1993
	(Equivalent Depth, In Feet)				
Observations	(22)	(21)	(14)	(20)	(77)
Mean	0.47	0.37	0.24	0.37	0.38
Standard Deviation	0.17	0.17	0.16	0.17	0.19
Minimum	0.10	0.05	0.03	0.04	0.03
Maximum	0.84	0.74	0.63	0.62	0.84

NOTE: *The number of observations in each year is included in parentheses. There are 25 subsurface drainage systems in Broadview, but 3 of these systems must be combined with other systems when estimating average drain water depths because it is not possible to isolate irrigation water deliveries to fields that are served by those systems. In years when all of the area drained by a drainage system is fallow, it is not possible to calculate an average depth, per unit of area irrigated. Hence, there are fewer than 22 observations in 1991, 1992, and 1993.*

The difference in mean drain water depths for 1986 through 1989, and 1990 through 1993, is statistically significant at the p=0.01 level.

Source: *Cone and Wichelns, 1994*

sufficient to indicate opportunities to improve farm-level water management practices.

Tables 7 and 8 also show the average decline in irrigation depth from 1990 through 1993 when tiered water pricing was fully implemented, as compared to 1986 through 1989 when it was not. The average decline was 3.28 to 2.46 feet for cotton and 2.01 to 1.81 feet for cantaloupe. A substantial decline also occurred in the maximum irrigation depth, which was 4.61 to 3.10 feet for grain and 4.61 to 4.23 feet for tomatoes. These reductions in irrigation depths indicate that many farmers in BWD have significantly altered water management practices.

Reductions in depth of applied irrigation water are reflected in reductions in average depth of drain water. The mean drain water depth declined from 0.71 feet in 1986 to 0.52 feet in 1989, 0.24 feet in 1992, and 0.37 feet in 1991 and 1993 (Table 9). Reductions in subsurface drain water volume have increased BWD's ability to manage tail water, commingled with subsurface drain water. The total volume of commingled drainage water has declined, with reduced subsurface drainage and recycled tail water, from about 14,000 af in 1986 to less than 2,000 af in 1992.

Tiered water pricing has effectively reduced drainage volumes in BWD and is now being implemented in other districts. On October 1, 1996, Panoche Water District started

The Grasslands Bypass Channel Project and SLD Use Agreement (implemented in 1996) is in an interim (5-year) plan which will improve delivery water quality and efficiency for the Grasslands wildlife areas (USBR, 1995). Implementing the Grasslands project will facilitate accomplishing the following SJVDP recommendations for the Grasslands subarea.

- requires and facilitates establishing a regional drainage entity to coordinate and jointly implement a subareawide drainage management system
- provides facilities to intercept about 20,000 af of unsuitable subsurface drainage, that previously moved through the Grasslands wildlife areas, and convey it to a renovated SLD
- requires developing water conservation plans, implementing source control and drainage reuse, and reducing deep percolation
- isolates drainage water in a single concrete lined channel that will provide more accurate monitoring of salt and selenium loads
- improves San Joaquin River water quality and reduces violation of CVRWQCB objectives

a tiered-water-pricing system for preirrigation. The first 9-inch depth of applied water will cost $50/af. Any water use over this amount will cost $100/af (*The Panoche Fan*, August 1996).

Improved Water Delivery Scheduling. The advance time period for water delivery scheduling in the Grasslands area has been reduced from 48 down to 6 to 8 hours, allowing growers greater flexibility in managing irrigation. Growers no longer have to pay for unused or rescheduled water, further promoting water conservation. Additional improvements in water delivery scheduling will require re-engineering of the delivery system.

Water Transfers and Marketing. Except for water transfers and purchase assistance in BWD, no extensive development of water transfers and marketing to reduce drainage has started. The subject is highly controversial.

Formation of Regional Drainage Management Organizations. As described earlier, a drainage management organization, now called Grasslands Area Farmers, was recently formed to implement the Grasslands Bypass Channel Project. This regional group drafted a regional management plan.

Unresolved Issues. Since 1990, only one drainage entity has been formed and tiered water pricing and improved water delivery scheduling has been adopted by limited number of districts. Further implementation of institutional changes are needed to resolve drainage problems in the Valley.

Drainage Water Treatment

At the beginning of SJVDP, major effort focused on treating drainage water for environmental or agricultural reuse. Selenium was the principal concern because of observed impacts and the lack of a known practical treatment method (other than high-cost reverse osmosis and other desalting methods). SJVDP investigated 11 treatment processes – 5 bacterial and 6 physical and chemical. The 1990 *Plan* summarized the results. Although selenium treatment was not recommended for large-scale implementation in the 1990 *Plan* because of developmental-stage technology, uncertain effectiveness, and high-cost concerns, a demonstration plant test for the anaerobic bacterial process was recommended.

DWR and the Bureau sponsored the Engineering Research Institute at California State University, Fresno, in establishing the Adams Avenue Agricultural Drainage Research Center in 1990. WWD provided 87 acres for this pilot-scale test facility near Tranquility in western Fresno County. The Center began testing in 1992 to reduce or remove selenium from drainage water, using upflow anaerobic sludge-blanket reactors, fluidized-bed reactors, and packed-bed reactors. In addition to the biological processes, a physical separation process using slow sand filtration was tested.

The principal test used upflow anaerobic sludge-blanket reactors. The influent water had a selenium concentration of 500 ppb. A selenium removal rate of about 90 percent was achieved, reducing the selenium concentration to 50 ppb or less during the summer months of 1994. Testing continued in 1995 with emphasis on perfecting the process and developing operational and feasibility data along with identification and characterization of process wastes. Testing was completed and the facility closed.

A laboratory-scale reactor system for selenium bioremediation by a newly discovered selenate-respiring bacterium, *Thauera selenatis*, was successfully developed by Joan Macy of the University of California, Davis. Selenium oxide concentrations were reduced from 350 to 450 ppb in drainage water to an average of 9.8 ppb, and as low as 5.4 ppb. *T. selenatis* can grow in water with a total dissolved solids of 30 parts per thousand, within the TDS content range of drainage reuse and evaporation pond water.

Experiments are underway to test a pilot-scale biological reactor system at the University of California, Berkeley and Lawrence Berkeley Laboratory experimental site near Firebaugh in the PDD. The experiments are designed to determine the least expensive carbon/energy source and optimal method to remove selenium from drainage water. UCB and LBL are also conducting a pilot-scale project sponsored by the Bureau and PDD to test an algal-bacterial treatment process for removing nitrate and selenite by precipitation from drainage water. Results of this pilot project are very promising.

Experiments and pilot projects are also ongoing for the microbial volatization of selenium from evaporation pond water. Teresa M. Fan of UCD has also conducted a laboratory-scale test of selenium volatization by aquatic plant species, a halophytic alga (*Chlorella*) and a common duckweed (*Lemna minor*). More than 70 percent of the selenium in 100,000 ppb selenite-containing water was removed by volatization and precipitation in trials. A pilot project to remove selenium from drainage water by wetland flow-through plant volatization prior to evaporation pond disposal is currently underway in TLDD. The latter is a cooperative study by TLDD and UCB. Various plant species, singly and in combination, are growing in each of ten wetland cells in the TLDD study. Preliminary results of selenium removal from drain water are encouraging.

Unresolved Issues. A full-scale drainage treatment system for selenium removal has not been constructed and put in operation, although laboratory and pilot-scale project results are encouraging. Efficiency, cost-effectiveness, and disposability or marketability of extracted selenium have not been established.

Monitoring

The 1990 *Plan* stated that an important premise underlying successful program implementation was long-term systematic monitoring of groundwater levels, soil conditions, land uses, water quality, drainage volumes, evaporation ponds, biota impacts, etc. At that time, monitoring was not conducted in a comprehensive, effective, or efficient manner.

SJVDIP developed a long-term monitoring plan, but has not fully implemented it because of funding shortfalls. Both SJVDIP agencies and local entities and growers, however, are monitoring drainage conditions and their impacts on a long-term systematic basis.

DWR's Agricultural Drainage Program employees monitor and evaluate drainage by collecting data on the occurrence and concentration of various constituents in agricultural drainage water and evaluating potential management solutions. Water quality and flow data are collected and evaluated from 29 subsurface drains and 2 surface drains throughout the Valley. Water quality data are maintained on file and used to estimate the quantity and quality of agricultural drainage water produced each year. DWR publishes the data annually in its report *San Joaquin Valley Drainage Monitoring Program*, which includes a contour map depicting depth to shallow groundwater in drainage problem areas based on data collected from about 1,000 wells.

DWR has begun a monitoring project on shallow groundwater, compiling a database of ground surface elevations, groundwater levels, and electrical conductivity measurements from 1,400 shallow wells in the Valley from 1988 to the present. The database is being used to develop a water level map for the Valley to determine potential "hot spots" where low crop yields could exist or be anticipated.

During 1997-1999, DWR will install additional clusters of monitoring wells to complete a monitoring network in the Tulare Basin. DWR is participating in a cooperative program with the Bureau to install equipment on the River to provide real-time data to help manage drainage releases to the River.

Unresolved Issues. Existing monitoring programs are hindered by lack of adequate funding. The effects of drainage reduction actions on soil salinity and crop productivity are not being adequately evaluated. Groundwater quality should be more closely monitored and funding should be provided to continue the monitoring.

Better coordination is also needed among government agencies and local entities to avoid duplication of effort, increase assurance of uniform procedures and standards with comprehensive monitoring, and compile all monitoring data effectively in a single publication.